

IAP20 Rec'd PG/PD 01 FEB 2006

A BOTTOM-TO-SURFACE CONNECTION DEVICE INCLUDING A
LEAKTIGHT FLEXIBLE JOINT BETWEEN A RISER AND A FLOAT

The present invention relates to the known field of bottom-to-surface connections of the type comprising a vertical undersea pipe referred to as a "riser" connecting the sea bottom to the surface, preferably going to a floating support installed on the surface.

Once the depth of water becomes large, a production field, and in particular an oil field, is generally worked from a floating support. The floating support generally includes anchor means for keeping it in position in spite of the effects of currents, winds, and swell. It also generally includes means for storing and processing oil and means for off-loading to off-loading tankers. Such floating supports are generally referred to as floating production storage off-loading (FPSO) supports. Numerous variants have been developed such as so-called SPARS which are long floating cigars held in position by catenary anchoring, or indeed "TLPs" which are platforms having tensioned anchor lines, said lines generally being vertical.

Wellheads are generally distributed over the entire field, and production pipes together with lines for injecting water and control cables are placed on the sea bottom converging on a fixed location, with the floating support being positioned vertically thereabove on the surface.

Some wells are situated vertically beneath the floating support and the inside of the well is then directly accessible from the surface. Under such circumstances, the wellhead fitted with its "Christmas tree" can be installed on the surface, on board the floating support. It is then possible from a derrick installed on said floating support to perform all of the drilling, production, and maintenance operations required on the well throughout its lifetime. The wellhead is then said to be "dry".

In order to keep the riser fitted with its dry wellhead substantially in its vertical position, it is necessary to exert upward traction thereon, which can be applied either by a tensioning system using cables and 5 winches or hydraulic actuators installed on the floating support, or else by floats distributed along the riser and installed at various depths, or indeed by using a combination of those two techniques.

The riser as tensioned by these floats is guided, 10 preferably relative to the floating support, by roller guides situated in a plane, preferably a single plane, enabling a riser to be held and guided relative to the floating support. Cable tensioning means acting as guide means can also be used.

15 FR 2 754 021 discloses a guide device for a riser provided with floats at its head end, the device including wheels enabling the riser to slide vertically, and also enabling it to turn about a horizontal axis so as to guide its horizontal displacements, so that 20 horizontal translation movements of the riser substantially follow those of the floating supports.

FR 99/10417 and WO/2001-11184 also disclose an improved 25 guide device having wheels and friction skids disposed radially around the pipe. That device for holding and guiding the portion of a vertical riser that is underwater and near the surface, in particular within a drilling bay, serves to minimize the reaction forces between said riser and the support structure secured to the barge. Finally, various guide systems are known that 30 involve tensioning by cable means.

Since the underwater depth of certain oil fields exceeds 1500 meters (m), and can be as great as 3000 m, the weight of risers over such depths requires forces to be used for holding them in position that can reach or 35 exceed several hundreds of (metric) tonnes. "Can_type" buoyancy elements are used that are added to underwater structures, mainly to risers connecting ultra-great

depths (1000 m - 3000 m) to the surface. The underwater pipe then consists in a rising column having an underwater pipe assembled to at least one float comprising a coaxial can surrounding said pipe with said pipe passing therethrough.

The floats in question are of large dimensions, and in particular they have a diameter of more than 5 m, a length of 10 m to 20 m, and possess buoyancy that can be as great as 1000 tonnes, and in general they are disposed as a string one beneath another.

The float and the pipe are subjected to the effects of swell and current, but since they are connected to the FPSO at the surface, they are also indirectly subjected to the effects of wind. This gives rise to lateral and vertical movements that are large (several meters) for the riser-float-barge combination, particularly in the zone that is subjected to swell. These movements generate large differential forces between the riser and the float. In addition, the bending applied to the riser leads to bending moments that are extremely large in the zone where there is a change in second moment of area, as arises whenever there is a connection between the riser and a float.

In order to minimize the forces generated by current and swell and acting on the riser-float combination, floats are generally circular and are installed coaxially around the riser.

In addition, floats are generally secured to the riser in such a manner that the riser-float connection provides sealing to said float so that it can confine a filler gas. The solution that is commonly used consists in embedding the float in the riser by welding, both at the top and at the bottom of the riser. Large amounts of reinforcement are added to ensure that the connection is sufficiently strong.

At such a connection between the riser and a float, the second moment of area changes considerably on passing

from the section of the riser to the section of the float.

These large variations in second moment of area lead to stresses being unevenly distributed, thereby generating very localized zones in which stresses can become unacceptable and can lead either to phenomena of sudden rupture, or else to phenomena of fatigue that in turn lead to cracks appearing, followed by collapse.

These localized stresses require transition pieces to be used to reinforce the weak zone, said pieces generally being conical in shape and of large dimensions, and being referred to as "tapered joints". In some circumstances, these pieces can be as much as 10 m long, and even under the best of circumstances they require the use of very high performance steels. However, it is often necessary to make use of titanium which is 5 to 10 times as expensive as the best steels. In addition, such pieces are generally complex in shape and they need to be made with extremely high quality so as to provide the expected service throughout the lifetime of the equipment, which lifetime can commonly exceed 25 years.

US patents Nos. 3 952 526 and 3 981 357 disclose junction systems between float-tanks and risers, in which use is made of parts made of elastomer material.

Those buoyancy systems make it possible to reduce the tensioning system situated on board the floating support, and they are generally distributed over a major fraction of the water depth, and in addition they present small buoyancy, generally a few hundreds of kilograms (kg) or possibly one or two tonnes.

The junctions are situated in the top portions of the floats, with the bottom portions of the floats generally being open. Such devices can transfer loads corresponding to lightening only a short length of the pipe, but they are not suitable for floats that are intended to support a very great length of riser, e.g. 500 m to 1000 m or even more, either alone or with the

help of additional tensioning systems secured to the floating support, where such lengths are to be found in very deep offshore oil fields, i.e. at depths of more than 1000 m. The buoyancy needed to achieve tensioning solely by means of floats requires considerable forces to be transferred vertically and transversely, and said vertical forces, when applied to the head of the riser, can reach several hundreds of tonnes, and can in particular lie in the range 300 tonnes to 500 tonnes.

In WO/2001-04454 in the name of the Applicant, there is disclosed a novel type of junction between the riser and the can that serves to support and transfer high loads, while mitigating the drawbacks of the above-mentioned floats assembled around said pipe by the pipe being embedded therein.

Those (riser-float) junction means are simple, flexible, and mechanically reliable, and they reduce the phenomena of fatigue and wear due to the stresses acting on the junction which is subjected to loads of several hundreds of tonnes.

More particularly, patent WO/2001-04454 in the name of the Applicant describes a string of floats surrounding a vertical riser, each of said floats being fitted at least one of its ends with a flexible joint comprising laminated abutments serving not only to provide sealing and to transfer loads, but also to decouple the second moment of area between the structures of said float and of said riser, so that there is practically no longer any zone in which stresses are concentrated at the transition between said float and said riser, thereby making it possible to reduce the complexity of the structure of the connection and also its own weight, thus significantly increasing the efficiency of the float, i.e. its buoyancy compared with its own weight.

Still more precisely, WO/2001-04454 describes junction devices between the riser and the float that comprise laminated abutments made up of layers of

elastomer sandwiched between rigid reinforcements, being supported by plates comprising a first plate secured to the pipe and a second plate secured to the float, with said rigid reinforcements and elastomer layers being:

- 5 - either in the form of superposed washers;
- or in the form of tubes or cylinders that are coaxial and adjacent.

In WO/2001-04454, the bottom-to-surface connection is thus continuous in the zone where the float is
10 installed, and the flexible junction serves to decouple the second moment of area of said float from that of said riser.

Current acts over the entire height of the riser, from the sea bottom up to its surface, but swell acts
15 only in a zone close to the surface and decreases in substantially exponential manner so as to become practically zero at a depth of about 80 m to about 120 m. Thus, when using a string of mutually independent floats as described in WO/2001-04454, the top floats are
20 subjected to considerable forces both laterally and vertically since the effects of swell are very large in zones close to the surface, while the bottom floats are subjected to much less stress. The unit dimensions of the floats are limited since they must be capable of
25 being handled on board the barge and then introduced into the derrick in order to be lowered through the drilling bay. Thus, in very great depth, e.g. of 2000 m to 3000 m, the weight of the riser is such that a large number of floats is required, e.g. four or five floats
30 presenting total buoyancy of 400 tonnes to 500 tonnes and extending over a height of about 100 m.

Each of the floats needs to be fitted with laminated abutments so as to minimize the transfer of stresses to the vertical riser which constitutes a highly critical
35 element of the bottom-to-surface connection since it must be capable not only of withstanding very high tensions, but also it must be capable of withstanding the bursting

pressure created by the fluid it transports, and also the implosion pressure created by the sea water.

This buoyancy, which is distributed as a multitude of independent floats, requires numerous laminated abutments to be used, each being of high cost. In addition, swell creates differential forces between pairs of adjacent floats, which forces are in addition to the considerable forces to which the riser is subjected at each discontinuity between the riser and a float.

It is thus desired to minimize the number of floats, but when the floats take on large dimensions, the transition zone between the bottom end of the float and the riser concentrates considerable horizontal thrust forces, thereby requiring said riser to be reinforced by a transition piece constituted by a conical forging of great length that is very difficult to fabricate and therefore very expensive, since it is generally made of very high performance metal, such as titanium. When there is only one float, it needs to be enormous when the depth of water is large, and the risk of failure associated with the transition piece then becomes very high and therefore unacceptable because of the high risk of pollution in the event of said bottom-to-surface connection failing or rupturing.

Furthermore, the entire riser behaves like a tensioned cord between the sea bottom and the point situated on the axis of the guide system relative to the floating support, and this leads to vibratory phenomena of the guitar-pendulum type. Water moving in the depth of the water creates drag effects on the structure of the riser and its floats, thereby generating large forces in varying directions, together with vibratory phenomena created by turbulence in the moving water separating from the riser.

Patent WO/2001-53651 in the name of the Applicant describes a device for stabilizing a bottom-to-surface connection of the type comprising a riser tensioned by a

float, said tensioned riser being guided at a surface support, preferably in a single plane. Said stabilization device serves to avoid vibratory phenomena of the guitar-pendulum type appearing, thus avoiding
5 localized accumulations of fatigue appearing in the steel as are usually to be encountered in the transition zone between the bottom of the float and the portion of the riser situated immediately below said float, said fatigue phenomena leading rapidly to cracking and then to rupture
10 of the installation.

Nevertheless, that stabilizer device does not make it possible to avoid having recourse to reinforced transition pieces, generally conical forgings of steel or titanium, where titanium presents particularly high
15 performance in terms of resistance to fatigue, but is particularly expensive because of its raw material cost and its difficulty of manufacture.

The object of the present invention is thus to provide a novel type of junction between a riser and a
20 float that improves the fatigue behavior in the zone that is the most highly stressed at the bottom end of the float, thereby reducing the probability of a phenomenon of the riser and/or the junction means being destroyed at said level.

25 Another object of the present invention is to provide a novel type of junction between a riser and a float that is simple to put into place when installing a bottom-to-surface connection device.

Another object of the present invention is to
30 provide a novel type of junction between a riser and a float that makes it possible to avoid having recourse to a reinforced transition piece in the zone between the bottom end of the float and the portion of the riser that is situated immediately therebelow.

35 Another object of the present invention is to provide the buoyancy of a bottom-to-surface connection device using a single float.

Another object of the present invention is to provide a novel type of junction between a riser and a float that makes it possible to monitor any possible cracking and thus to monitor loss of sealing from the 5 riser in said junction zone and/or in the junction means themselves.

To do this, the present invention provides a bottom-to-surface connection device comprising at least one undersea pipe or riser including at least one float and 10 possibly including only one float, said float being connected at its bottom end to a junction device creating a leaktight flexible joint between the bottom end of the float and said riser, the connection device being characterized in that said junction device is interposed 15 between and secured to a bottom portion of the riser going down to the sea bottom and a top portion of the riser passing through said float and rising to the surface, said junction device comprising at least:

- a first forged body of revolution secured to the 20 top end of said bottom portion of the riser, and forming an internal tubular duct section having substantially the same diameter as said bottom portion of the riser; and

- a second forged body of revolution secured to the bottom end of said top portion of the riser, and forming 25 an internal tubular duct section having substantially the same diameter as said top portion of the riser;

- said first and second forged bodies being interconnected in flexible and leaktight manner by at least a first flange in the form of a body of revolution 30 secured in leaktight and reversible manner to said second forged body and connected to said first forged body by at least a first laminated abutment in the form of a body of revolution, comprising a plurality of elastomer layers interposed between rigid reinforcements preferably made 35 of metal defining surfaces of revolution having the same axis as the common longitudinal axis of revolution ZZ' of said first and second forged bodies and said first

flange, said surfaces of revolution being frustoconical in shape or skew surfaces, such as surfaces of sections that are ellipsoidal, preferably spherical, or parabolic or hyperbolic or in shape.

5 The axis of symmetry and the axis of revolution ZZ' coincide when the junction device is in the rest position.

10 The term "surface of revolution of ellipsoidal, parabolic, or hyperbolic section" is used herein to mean a surface of revolution that is respectively ellipsoidal, parabolic, or hyperbolic and that is defined by two parallel section planes perpendicular to said axis of revolution ZZ'.

15 By means of the structure of the junction device, and in particular the shape of the layers of elastomer in said laminated abutments that are frustoconical or spherical in shape, the hinged connection of the present invention makes pivoting movements possible in association with a self-centering effect. As a result, 20 overall, the stresses and the deformations generated at said laminated abutments and said forged bodies are minimized and make it possible to maintain or to restore a substantially aligned position for the top and bottom portions of said riser.

25 Thus, the junction device of the present invention is suitable for providing the junction between the riser and a single large tensioning float in a manner that is reliable, whereas the junction devices described in WO/2001-04454 are suitable only for providing a junction 30 between the riser and small floats disposed as a string.

More particularly, a bottom-to-surface connection device of the invention comprises an undersea pipe or riser tensioned by at least one float constituted by a can presenting a cylindrical casing surrounding said pipe 35 coaxially, located on the high underwater portion of said pipe, said pipe preferably being held and guided by a surface guide device located at a floating support and

including a said junction device for said can, the connection device being characterized in that:

- said first forged body presents in its top portion an outer first surface of revolution that is preferably frustoconical in shape or of ellipsoidal section; and

5 - said second forged body of revolution secured to the bottom end of said top portion of the riser, preferably by welding, presents in its bottom portion a bottom first surface; and

10 - said first flange presents:

• an inner first surface of revolution of frustoconical shape or of ellipsoidal section, said inner first surface of the first flange and said outer first surface of the first forged body being situated facing each other and co-operating elastically and in leaktight manner via a said first laminated abutment in the form of a body of revolution that is frustoconical in shape or respectively of ellipsoidal section, comprising a plurality of layers of elastomer sandwiched between reinforcing sheets of rigid material, in particular steel sheets, bonded to said inner first surface and said outer first surface thus bonding together said first flange and said first forged body; and

25 • at least a portion of a top surface of said first flange co-operating in leaktight manner, preferably via at least one O-ring, with said bottom surface of said second forged body of revolution, said top surface portion of said first flange and said top surface of said second forged body being secured to each other in leaktight and reversible manner, preferably by bolting; and

30 - said outer casing of the float being secured to a top surface of said second forged body or to a top surface of a second flange in the form of a body of revolution having a bottom surface, itself bonded in leaktight and reversible manner, preferably by bolting

and via at least one O-ring, to a portion of said top surface of revolution of said first flange.

Preferably, said top and bottom surfaces of said first and second flanges and of said second forged body 5 are annular plane surfaces or surfaces of revolution, said first and second forged bodies and said first flange, and where appropriate said second flange, and said annular plane surfaces or surfaces of revolution all have a common axis of symmetry or of revolution ZZ' when 10 in the rest position.

Still more particularly, said second forged body of revolution includes in its bottom portion an outer second surface of frustoconical shape or preferably of ellipsoidal section, and said outer second surface of 15 revolution is situated facing and co-operates elastically and in leaktight manner with an inner second surface of revolution of frustoconical shape or respectively of ellipsoidal section, said inner second surface being situated in the top portion of said second forged body, 20 and said inner second surface being connected to said outer second surface via a second laminated abutment in the form of a body of revolution constituted by a plurality of elastomer layers sandwiched between rigid reinforcing sheets, in particular of steel, that are 25 frustoconical in shape or respectively of ellipsoidal section, and that are bonded to said outer second surface and to said inner second surface.

In a first particular variant, said first abutment and where appropriate said second abutment, said outer 30 first surface of the first forged body, said inner first surface of the first flange, and, where appropriate said outer second surface of revolution of the second forged body, and said inner second surface of revolution of the first forged body are all frustoconical in shape about 35 the same said axis of revolution ZZ', with an angle of the apex β lying in the range 30° to 80° , preferably in the range 40° to 70° , the apexes of the various

frustoconical surfaces being situated below said frustoconical surfaces, and the various frustoconical surfaces either sharing a common angle at the apex β or a common apex C.

5 It will be understood that either said truncated cones flare upwards and converge substantially on a single point C, in which case they present an angle at the apex β that varies from one cone to another, or else they have the same angle at the apex, with their apexes 10 then being distributed substantially along said axis of revolution ZZ'.

In a preferred second particular variant, said first abutment, and, where appropriate said second abutment, 15 said outer first surface of the first forged body, said inner first surface of the first flange, and, where appropriate said outer second surface of revolution of the second forged body, and said inner second surface of revolution of the first forged body are all of ellipsoidal section, preferably of spherical section, all 20 being substantially centered on the common point O situated above said surfaces and on said axis of revolution ZZ'.

By means of its makeup interposed between the two riser portions and comprising various forged bodies and 25 flanges secured to one another, the junction device of the present invention is particularly easy to put into place when installing the bottom-to-surface connection device.

Furthermore, and above all, the junction device of 30 the present invention provides a leaktight flexible joint that is particularly effective, since during movement of the float associated with the riser due to swell and current, the articulated connection between the float and the riser can accommodate pivoting while keeping the 35 bottom portion of the riser in tension. The preferably spherical shape of said first laminated abutments in accordance with the invention has a self-centering

effect, and the entire tensioning force created by the float (which can exceed 500 tonnes) is transferred to the riser in a manner that is uniformly distributed merely by deformation. When the connection device takes on an 5 angle α , the deformation in the laminated abutments remains substantially uniform and the stresses generated within the various components of the laminated abutments also remain substantially uniform.

Said angle α that results from the laminated 10 abutment deforming preferably lies in the range 0° to 5° .

It will be understood that when it is stated in the present application that the axes of revolution of the various components and surfaces are the same, it should be understood that the axes of revolution of said first 15 and second forged bodies coincide and likewise the axes of revolution of the flanges and of the surfaces of revolution also coincide, providing the structure is at rest, i.e. when there is no bending, as is made possible by said flexible joint device of the invention.

Said laminated abutment enhances the self-centering 20 effect and the load take-up effect of the first laminated abutment, while also enhancing the primary sealing function so that in an advantageous embodiment, said first and second forged bodies and said first flange 25 define between them a first internal chamber which preferably co-operates with means for monitoring the pressure inside said chamber.

More precisely, said first chamber is defined by the top portion of said first forged body and by the free 30 portions of said bottom surface of revolution of said second forged body, said concave inner first surface of revolution of said first flange, and said convex outer second surface of revolution of said second forged body.

Said inner chamber fitted with pressure monitoring 35 means makes it possible to monitor degradations and/or losses of sealing through one of the laminated abutments, or indeed cracking in one of the components of the

junction device including the leaktight joint, and/or the riser. When the pressure in said chamber varies, the operators are warned of an imminent danger and can take action, given that the general structure of said junction device includes a plurality of bodies and flanges that are secured to one another in reversible manner.

In an advantageous embodiment, said top surface portion of the first flange and said bottom surface of the second forged body, and where appropriate said bottom surface of the second flange, are all plane annular surfaces.

In a preferred embodiment of the invention, said outer casing of the float is secured to an internal second pipe of greater diameter than said riser, said internal second pipe preferably being a reinforced pipe of thickness greater than said riser; and it includes a said second flange in the form of a body of revolution to which the bottom end of said outer casing of the float and the bottom end of said internal second pipe are secured, preferably by welding, said second flange surrounding said second forged body so that a second inner chamber is defined by an inner surface of revolution of said second flange having the same axis of revolution ZZ', by said top surface of revolution of said second forged body), by the cylindrical outer surface of said top portion of the riser and the cylindrical inner surface of said internal second pipe, and by a closure flange at the top ends of said internal second pipe and of said top portion of the riser, said second chamber preferably co-operating with means for monitoring the pressure inside said second chamber.

This embodiment makes it possible to monitor and reveal leaks caused by cracking in the various components of the junction device and the risers and pipes, or indeed mere failures to achieve sealing, while still ensuring that the buoyancy of the float is maintained.

Also preferably, said internal second pipe extends above said float, preferably in the form of a reinforced pipe of thickness greater than said riser which it surrounds, and preferably a holding and guide device 5 serves to guide said internal second pipe relative to said floating support.

Furthermore, said reinforced internal pipe extends above said riser and co-operates with the holding and guiding device so as to take load off the top portion of 10 the riser in its underwater portion and in particular so as to avoid phenomena of said top portion buckling as a result of the pressure and the temperature of the fluid that it might be conveying.

According to the present invention the top end of 15 the float is secured to the top portion of the riser or of said internal second pipe via a rigid junction.

In an advantageous embodiment, said float is a single float extending over a length of 40 m to 100 m in order to confer buoyancy enabling the entire bottom-to- 20 surface connection to be tensioned, said float preferably being made up of segments that are assembled to one another, each constituted by a cylindrical box, which boxes are preferably individually sealed, and secured mechanically to one another in the longitudinal direction 25 ZZ'.

Also advantageously, the buoyancy of said undersea pipe is provided by said float without adding any additional tensioning system that is secured to the floating support.

Installing the junction device of the invention with 30 a leaktight flexible joint at the bottom of the float does not significantly alter the behavior of the connection device concerning vibration phenomena of the pendulum-guitar type described in WO/2001-53651, thereby 35 advantageously eliminating the appearance of such phenomena, providing the device of the invention includes stabilizer means in the bottom portion of the float

having the effect of increasing the mass of water it entrains when it moves, or lowering the center of gravity of the top portion of the pipe in the vicinity of the float.

5 More particularly, the device of the invention includes stabilizer means comprising a helical ramp surrounding said float in its bottom portion close to its bottom end, and/or an additional peripheral mass situated around the bottom portion of the float.

10 Other characteristics and advantages of the present invention appear in the light of the following detailed description given with reference to the accompanying figures, in which:

15 - Figure 1 is a side view of a bottom-to-surface connection device of the invention;

- Figures 2 and 3 are section views through the bottom portion of the float, showing the various components of a junction device of the invention having a flexible leaktight joint;

20 - Figures 4 and 5 are section views of two other embodiments of a junction device of the present invention having a leaktight flexible joint;

- Figure 6 is a section view through a device of the invention as shown in Figure 2, further including a drill string during a well-drilling operation;

25 - Figure 7 is a section view of a device of the invention as shown in Figure 2, further including a second riser for safety purposes having a production line installed therein;

30 - Figure 8 is a side view similar to Figure 1, the bottom-to-surface connection device being fitted with an additional mass at the bottom of the float close to the junction device having a leaktight flexible joint;

35 - Figure 9 is a side view similar to Figure 1, in which the bottom-to-surface connection device is fitted with anti-vortex fins in the bottom portion of the box-

type float close to the junction device of the invention having a leaktight flexible joint;

- Figure 10 shows a variant of the connection between the first laminated abutment and the first flange; and

- Figure 11 shows a variant embodiment with surfaces that are frustoconical in shape.

Figure 1 shows a bottom-to-surface connection device of the invention comprising a riser 1 having a box-type float 2 made up of segments 2₁-2₇, suitable for being handled on board a barge or floating support 10 in order to be assembled, in particular within a drilling bay 12, and thus building up a single float. More precisely, the segments are constituted by cylindrical boxes 2₁-2₇, each of which is individually hermetically sealed, the boxes being mechanically secured to one another in the longitudinal direction ZZ'. Said float 2 extends over a length of 40 m to 100 m in order to confer buoyancy that enables the entire bottom-to-surface connection to be tensioned.

The float 2 is thus constituted overall by a can presenting an essentially cylindrical casing 20 disposed coaxially around the top portion 1b of the riser 1, at the underwater top end of the pipe 1. The riser opens out at the surface inside a drilling bay 2 of a floating support or barge 10 that supports processing equipment 11. The bottom portion 1a of the riser 1 that extends below the float 2 is of substantially constant diameter down to the sea bottom.

The top portion 1b of the riser above the float 2 is surrounded by a reinforced pipe 3 secured to said float 2. Thus, it is said reinforced pipe 3 that is held and guided by a guide system comprising a known roller device 4 secured to a structure 6 connecting it to said barge 10. The guide device 4 allows the reinforced pipe 3 to slide, and thus allows said riser to slide along its longitudinal axis, and it guides it lateral movements in

a horizontal plane perpendicular to said longitudinal axis ZZ' of the riser 1.

In Figure 1, there is shown diagrammatically a junction device 8 creating a leaktight flexible joint between the bottom end of the float 2 and said riser 1. The top end of the float 2 is secured to said reinforced pipe 3 via a rigid junction 8₁.

Figures 2 and 3 show a preferred embodiment of a junction device 8 of the invention having a leaktight and flexible joint.

The junction device 8 of the invention is interposed between a bottom portion 1a of the riser going down to the sea bottom and a top portion 1b of the riser passing through the float 2 and rising to the surface.

The term "shape of spherical section centered on O" is used below to mean a shape that can be inscribed in a casing of spherical section constituted by a surface of revolution defined between two parallel horizontal section planes and situated in the same hemisphere of a sphere of center O, said center O being placed above said parallel horizontal section planes.

The junction device 8 in Figures 2 and 3 comprises:
- a first forged body of revolution 22 having its bottom end secured by welding 22a to the top end of the bottom portion 1a of the riser, this first forged body of revolution 22 forming an internal tubular duct section 22₃ having substantially the same diameter as the said bottom portion 1a of the riser to which it is secured by a complete peripheral weld 22a; said first forged body 22 presents in its top portion a flared shape forming a convex outer first surface of revolution 22₁ in the shape of a spherical section centered on a point O situated substantially on the longitudinal axis ZZ' of said riser, and a concave inner second surface of revolution 22₂, in the shape of a spherical section of diameter greater than the inside diameter of the riser 1 and of diameter

smaller than said convex outer surface of revolution 22₁, and substantially centered on the same point O;

5 - a second forged body of revolution 24 whose top end is welded at 24a over its entire periphery to the bottom end of said top portion 1b of the riser, said second forged body of revolution 24 forming an internal tubular duct section 24₄ of substantially the same diameter as said top portion 1b of the riser; said second forged body of revolution 24 further presenting in its
10 bottom portion a bottom first surface 24₁ comprising a plane annular portion, and a convex outer second surface 24₃, in the shape of a spherical section of diameter smaller than that of said spherical section of said concave internal surface 22₂, substantially centered on
15 the same point O as said other spherical section surfaces 22₁, 22₂, said convex outer second surface 24₃, being situated at a level below said bottom first surface 24₁ and constituting the bottom end of the outer surface of said second forge body 24;

20 - a first flange 23 in the form of a body of revolution presenting a concave internal first surface 23₁ of revolution of spherical section substantially centered on the same point O as said other spherical section surfaces 22₁, 22₂, and 24₃, and said first flange 23 also presents an annular plane top surface 23₂; and

25 - a second flange 21 in the form of a body of revolution having an annular plane bottom surface 21₂, together with an annular plane top outer surface 21₁ and an inner surface of revolution 21₃.

30 Said second flange 21 in the form of a body of revolution provides a connection between the bottom end of the cylindrical outer casing 20 of the float 2 and an internal pipe 3 in said float that contains said top portion 1b of the riser coaxially therein. Said internal pipe 3 is a reinforced pipe of greater diameter and greater thickness than the riser 1 and it is extended at its top end to protect the riser 1 in the vicinity of the

holder and guide device 4 in the drilling bay 12. Said second flange 21 is secured to the bottom end of the outer casing 20 by a peripheral weld 21b and to the bottom end of said internal pipe 3 by a peripheral weld 21a. Said second flange 21 surrounds said second forged body 24.

The various forged bodies 22 & 24 and flanges 21 & 23 are assembled together and they co-operate as follows in order to provide a junction device having a leaktight and flexible joint:

- said concave inner first surface 23₁ of the first flange 23 and said convex outer first surface 22₁ of the first forged body 22 co-operate elastically and in leaktight manner via a first laminated abutment 30 in the form of a body of revolution in the shape of a spherical section centered substantially on the same point O, comprising a plurality of layers of elastomer sandwiched between reinforcement of steel sheets with end sheets bonded to said concave inner first surface 23₁ and said convex outer first surface 22₁, thus providing a direct connection comprising a leaktight and flexible joint between said first flange 23 and said first forged body 22;

- said annular plane top surface 23₂ of the first flange 23 is secured in leaktight and reversible manner to the plane portion of the bottom surface 24₁ of the second forged body 24 by bolting in holes 27 in said first flanges 23 and forged bodies 24, with sealing being provided by interposed O-rings 28;

- said plane top surface 23₂ of said first flange 23 is likewise secured in leaktight and reversible manner to the annular plane bottom surface 21₂ of said second flange 21 by bolting in holes 25 in said first and second flanges 21 and 23, with sealing being provided by O-rings 28 interposed between said surfaces 23₂ and 24₁; and

- said concave inner second surface of revolution 22₂ in the shape of a spherical section of said first forged

body 22 is connected to said concave outer second surface 24₃ of said second forged body 24 via a second laminated abutment 31 in the form of a body of revolution constituted by a plurality of layers of elastomer 5 sandwiched between rigid reinforcements of steel sheet, the end reinforcements being bonded to said convex outer second surface 24₃ and to said concave inner surface 22₂, thus providing a direct, flexible, and leaktight connection between the two forged bodies 22 and 24.

10 Laminated abutments made up of layers of elastomer and rigid reinforcement are well known to the person skilled in the art.

15 It will be understood that said concave and convex surfaces of spherical section have their concave sides facing upwards and their convex sides facing downwards, i.e. they can be inscribed in a hemisphere having a bottom horizontal section.

20 In Figures 2 and 3, a first leaktight internal chamber 40 is defined by the top margin 22₄ of said first forged body 22 and the sides of said first and second laminated abutments 30 and 31 and the free portions of 25 the bottom surfaces 24₁ of the second forged body 24, said concave inner first surface of revolution 23₁ of the first flange 23, and said convex outer second surface of revolution 24₃ of the second forged body 24. The chamber 40 is fitted with pressure monitoring means, e.g. an external pressure gauge 42 connected to the chamber 40 via a duct 41 passing through the flange 23, or a pressure sensor connected to the control cabin of the 30 barge.

A second leaktight chamber 45 is defined by the top closure flange 5, the cylindrical outer surface 1₁ of the top portion 1b of the riser, the cylindrical inside surface 3₁ of the reinforced internal pipe 3, and the 35 inner surface of revolution 21₃ of the second flange 21 and the top outer surface 24₂ of the second forged body 24. The second chamber 45 also co-operates with an

external pressure sensor or gauge connected to said chamber via a duct 48 passing through the flange 21.

During movements of the float 2 associated with the riser 1, due to swell or to current, the jointed connection device 8 between the float and the riser allows a certain amount of pivoting to take place, while keeping the bottom portion 1a of the riser under tension. The spherical shape of said first and second laminated abutments 30 and 31 has an automatic centering effect, and the entire tensioning force created by the float (which might displace 500 tonnes) is transferred to the riser merely by said laminated abutments being deformed in compression.

The second laminated abutment 31 acts mainly as a primary seal, with the major fraction of vertical load transfer taking place via the first laminated abutment 30.

Said reinforced pipe 3 at the top of the float 2 can be assembled to an internal second pipe 3 inside the float, which second pipe need not be reinforced, with assembly being implemented in conventional manner using stiffeners, since the forces in this zone are much smaller than in the bottom portion.

In a simplified version of the invention shown in detail in Figure 4, the second laminated abutment 31 providing primary sealing as shown in Figure 3 is omitted. The first laminated abutment 30 then both provides primary sealing and also transfers vertical and horizontal loads between the float and the riser. In this simplified version, the pressure monitoring chamber 40 of Figures 2 and 3 no longer exists, and it is therefore not possible to detect leaks therein.

In another simplified version of the invention shown in detail in Figure 5, the second forged body 24 and the second flange 21 of Figures 2 and 3 are combined in a single forged body 24 having the bottom end of the outer casing 20 of the float 2, and the bottom end of the riser

1b welded directly to its top surface 24₂ at 24b; in this configuration there is no longer an internal second pipe 3 surrounding said top portion 1b of the riser 1 coaxially. In this simplified version, the pressure monitoring chamber 45 of Figures 2 and 3 no longer exists, and it is therefore not possible in simple manner to detect locally any leaks from the riser in this zone.

Figure 3 shows the assembly inclined at an angle of value α between the top portion 1b and the bottom portion 1a of the riser.

In the descriptions of Figures 2 to 4, the laminated abutments as described as being spherical and as co-operating with the spherical bearing surfaces of the forged and machined flanges and bodies 22, 23, and 24, the set of spheres and spherical bearing surfaces then being described as having a common center O.

In fact, when fabricating those elements, it can be considered that the point O is indeed common to each of the above-described spherical bearing surfaces; however, during installation on site, the laminated abutments are subjected to considerable forces, which may reach or exceed 500 tonnes, so they deform in very significant manner, e.g. by a few centimeters, and consequently the reference centers O of some of the components moves vertically relative to the reference centers of other components. Nevertheless, it can be considered that in fact the reference centers of the various spherical bearing surfaces remain substantially centered at the common point O. Similarly, during tilting through an angle α , as shown in Figure 3, the various reference points of the spherical bearing surfaces are shifted sideways a little, but nevertheless remain substantially centered on O.

Figure 6 shows the device of the invention during a "single-casing" drilling operation. A string of rods 50 with a drilling tool installed at its bottom end is set into rotation. Drilling mud is injected under pressure

inside the drill string 51, and then rises together with drilling debris up the annular space 52 between the riser 1 and the drill string 50.

Figure 7 shows a "double-casing" variant. Inside the riser 1, there is advantageously installed a safety pipe 55 made up of unit lengths that are connected to one another end-to-end by screw fastening. A production line or drill string 50 is situated inside this additional casing.

In this configuration, during drilling operations, mud carrying drilling debris rises to the surface inside said safety pipe 55 and therefore does not come into contact with the riser 1, nor with the laminated abutment 31. This second casing constitutes a primary barrier in the event of pressure rising due to the well erupting or to any other accident, the riser 1 then constituting the outer barrier that serves mainly to withstand the outside pressure due to sea water, and also to the traction exerted by the tensioning buoys. This disposition enables the safety of the installation to be increased considerably, but it presents the drawbacks of increasing its overall weight, which needs to be compensated by increasing the total buoyancy volume.

In Figures 6 and 7, the drill strings 50 and the additional casing 55 are continuous through the flexible joint zone situated at the bottom portion of the float. Pivoting through the angle α at the bottom of the float, as shown in Figure 3, takes place through very small angles, of the order of 2° to 4° at the most, and said drill strings 50 and additional casing 55 can take up the necessary curvature without unacceptable stresses because of the clearance that exists relative to the riser 1, given that they are of much smaller diameter.

Including a leaktight joint 8 at the bottom of the float does not significantly modify the overall behavior of the assembly with respect to vibration phenomena of the pendulum-guitar type as described in patent WO/2001-

53651 in the name of the Applicant, and the appearance of such phenomena is advantageously eliminated by installing as close as possible to said joint either an added peripheral weight 60 situated around the bottom portion 5 of the float 2 as shown in Figure 8, or antivortex type fins 61 providing a helical ramp 61 surrounding said float 2 in its bottom portion 2, close to its bottom end, as shown in Figure 9.

By way of illustration, the dimensions of a junction 10 device 8 of the invention can be as follows:

- between the bottom end of the first forged body 22 and the top end of the second forged body 24 the distance is about 60 centimeters (cm);

15 - the inside diameter of the riser 1 is about 400 millimeters (mm);

- the outside diameter of said first and second flanges 21 and 23 is about 140 cm; and

20 - the nominal diameter of the mean sphere corresponding to the first leaktight abutment 30 is about 70 cm to 90 cm and its thickness is 6 cm to 15 cm depending on the load to be transmitted and the pivot angle α .

In order to simplify fabrication of the first laminated abutment 30, the flange 23 is advantageously 25 made as two portions 23a and 23b as shown in Figure 10. An O-ring 23c provides sealing between the two portions. The laminated abutments and the surfaces of the various flanges form bodies and surfaces of revolution that are defined as being spheres of center O, however it remains 30 within the spirit of the invention if conical shapes are used, as shown in Figure 11.

Figure 11 shows a variant embodiment with the surfaces of spherical shape replaced by surfaces of frustoconical shape.

35 In the right-hand side of Figure 11, the apexes of said cones converge substantially on a single point C, with the cones then all being different from one another

since the angle at the apex β varies from one cone to another.

In the left-hand side of the same Figure 11, said cones all have the same angle of the apex β and they are therefore all identical, with the apexes of the various cones then being distributed substantially around the axis ZZ'.

Nevertheless, it is preferred to use shapes that are spherical, since with conical shapes, when the joint takes on a large angle α , the laminated abutments can become pinched and then cease operating in uniform manner.

Said first and second laminated abutments 30 and 31 can accommodate bending through an angle α relative to said longitudinal axis ZZ' having a value lying in the range 0 to 5°, and more usually 0 to 2°.

The junction device 8 of the present invention can be manufactured and put into place using the following sequence:

20 1) a first layer of uncured elastomer or a first rigid reinforcement, preferably made of metal, is bonded to said inner first surface 23₁ of said first flange 23;

25 2) the various layers of non-cured elastomer and of rigid reinforcement making up said first laminated abutment 30 are installed and bonded in succession;

30 3) said first forged body 22 is put into place, being bonded via its said outer surface 21 to the last layer or last rigid reinforcement of said first laminated abutment 30;

35 4) at least one O-ring 28 is put into place on a said top surface of revolution 23₂ of said first flange 23;

5) said second forged body 24 is put into place causing it to rest via its said plane bottom surface 24₁ on said top surface of revolution 23₂ of said first flange 23;

6) where appropriate, a first elastomer layer or rigid reinforcement is installed and bonded on said inner second surface 22₂ of said first forged body 22 and then the various layers of non-cured elastomer and the various 5 rigid reinforcements of said second laminated abutment 31 are installed in succession;

7) said second forged body 24 is bonded via its said outer second surface 24₃ onto the last layer or reinforcement of said second laminated abutment 31;

10 8) said first flange and said second forged body 24 are united by bolting;

9) the assembly is heated in an oven to cure the various layers of elastomer;

10) the riser portions 1a and 1b are assembled 15 together in conventional manner by being welded to the respective forged bodies 22 and 24; and then

11) the bottom end of the casing of the last float 20 is welded to the top surface 24₂ of the second forged body 24 or to a top surface 21₁ of a second flange 21, 20 said flange having a bottom surface 21₂, itself bolted to a peripheral portion of said top surface 23₂ of said first flange 23 after initially installing at least one O-ring 26 between the two surfaces.

When using frustoconical laminated abutments, i.e. 25 having metal reinforcement and elastomer layers that are frustoconical in shape, these are easier to make since the surface can be developed on a plane, which is not true of other shapes whether they be elliptical, spherical, parabolic, or hyperbolic, which other shapes 30 require precision stamping operations that are more difficult to perform.

In an advantageous embodiment that facilitates 35 installing and assembling the junction device 8 of the invention, said first flange 23 comprises two portions 23a and 23b, in which the first portion 23a is a body of revolution including said inner first surface 23₁, and said second portion 23b is a peripheral flange comprising

said top surface 23₂, said second portion 23b being secured in leaktight and reversible manner to said first portion 23a via at least one O-ring 29 by securing said top surface portion 23₂ of the first flange 23 in 5 leaktight and reversible manner to said bottom surface 24₁ of said second forged body 24.

In an advantageous embodiment, the junction device 8 is put into place and manufactured by bonding said first laminated abutment 30 onto a first portion 23a of said 10 first flange 23, said first portion 23a being a body of revolution including an inner surface corresponding to said inner first surface of revolution 23₁.

The following assembly steps are then performed:

1) said first laminated abutment 30 is bonded to 15 said body of revolution 23a;

2) the first forged body 22 is bonded via its said outer surface 22₁ to the free face of said laminated abutment 30;

3) said second laminated abutment 31 is bonded to 20 said inner second surface 22₂ of the first forged body 22;

4) said outer second surface of revolution 24₃ of the second forged body 24 is bonded to the free face of said second laminated abutment 31;

5) the assembly is put into an oven in order to cure 25 the various layers of elastomer; and then

6) a second portion 23b of said first flange 23 comprising both said top surface portion 23₂ co-operating in leaktight manner via an O-ring 28 with said bottom surface 24₁ of the second forged body 24, and also a 30 concave surface 23c capable of co-operating with the free outer face of said first portion 23a via an O-ring 29 is bolted to the second forged body 24, and where appropriate to a said second flange 21, the first portion 23a of the first flange 23 thus also being prevented from 35 moving and the entire junction device 8 thus being united.

The advantage of this embodiment is that it makes it possible to verify that the layers constituting the edges 30a and 31a of said first and second laminated abutments 30 and 31 have been properly cured.

5 The forged bodies 22 and 24 and the flanges 21 and 23 are described as being bodies of revolution, however it would remain the spirit of the invention for those parts to present external shapes that are polygonal or irregular, it is only the surfaces 23₁, 22₁, 22₂, and 24₃,
10 which receive the laminated abutments that need to be substantially spherical about a center O, or ellipsoidal, or indeed conical, as described above.